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AUTHOR Rhoneck, Christoph von
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ABSTRACT

In a German study, students' descriptions of the processes in an electric circuit were related to the energy view as it is used in physics. (The representation of students' concepts describing the electric circuit is of importance because structured concepts may influence the perception and description of processes, the handling of electrical devices, and the assimilation of physical concepts.) It was shown that students generally do not distinguish between the circulating current and the unidirectional energy flow. Usually, students related current, bulb, and battery in a way that forms the students' so-called energy view. Several simple tasks were applied to isolate the correct information from information that is compatible with the student's energy view. The concept mapping of results showed a dominant students' energy view before and after instruction. Better results were obtained when the different views were explicitly taught. These recommendations for teachers were made: to present information on single concepts as well as on integrating views, to isolate situations that run counter to the student's representation and to produce a conflict between it and prospective learning materials, and to develop the different aspects of a voltage concept. (YLB)

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Semantic Structures Describing the Electric Circuit and Their Influence for the Inprovement of Teaching

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Christoph von Rhöneck

Summary

In order to study the internal representations of the electric circuit different methods were used. Tiberghien and Delacôte, Osborne, and Andersson mainly focused on the manipulatory strategies of students in connection with simple electric circuits. Similar results were obtained which may be summarized as a linear causal effect between battery and bulb (Tiberghien and Delacôte) or as a source-consumer model for electric circuits (Andersson). Maichle and Rhöneck used another approach and studied the semantic structures of the more or less distinctive students' concepts which are used to describe electric phenomena. Maichle analyzed the representation on the basis of network theory. The author's study based on the different concepts which are used in physics.

The latter interpretation shows that students generally do not distinguish between the circulating current and the unidirectional energy flow. Usually the students relate current, bulb, and battery in a way which forms the so-called students' energy view. Several simple tasks were applied to isolate the correct information from information which is compatible with the students' energy view. When the test results are combined a structure becomes visible. The concept mapping of the results shows a dominant students' energy view before and even after instruction. Better results were obtained when the different views were explicitely taught. The teacher should be aware of the necessity to present information on single concepts as well as on integrating views.

Another element in search of better teaching methods ist to isolate such situations which run counter to the student's representation. In this way a conflict may be produced between prospective learning materials and the student's representation. Those conflicts may be used to analyze the argumentation which usually hinders the development of a more adequate representation. A special conflict situation is to be expected when the student gets in touch with i=const. The invariability of current around a circuit rests an intelligible constraint as long as current means energy.

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A third important perspective for teaching is related to the introduction of voltage. Generally, the concept of voltage is not developed as an independent concept in a first period of instruction. Even more advanced students usually do not use the voltage concept when their problem-solving strategies are analyzed. For that reason specific efforts are necessary for the development of the different aspects of a voltage concept.

1. Introduction

The representations of students' concepts describing the electric circuit is of importance because structured concepts may influence the perception and description of processes, the handling of electrical devices and the assimilation of physical concepts. These aspects were studied by different methods and led to complementary results.

Tiberghien and Delacôte, 1976, used a manipulatory analysis of very simple circuits and described the representation of the phenomena. As their most essential result Tiberghien and Delacôte emphasized that the battery acts on the bulb in a linear causal effect. Similar results were obtained by Osborne, 1983, and Andersson, 1980.

The semantic information of the more or less distinctive students' concepts which were used to describe electric phenomena before instruction was studied in Germany. The outcomes of these studies may be interpreted in different ways. Maichle, 1981, analyzed the representations as semantic networks on the basis of network theory (Norman et al., 1975). In this study the students' descriptions of the processes in a circuit will be related to the energy view as it is used in physics. In a first step the processes are described concisely. Afterwards empirical results will be reported and the relation to the description in physics will be drawn.

2. Comment on the description of the electric circuit in physics

The electric circuit may be explained as a system where energy is transformed, or as a system where voltages are measured and currents flow. In the energy view (v. fig. 1. a) the battery is the place where energy is stored and where it is transformed from chemical into electrical energy. From here the energy flows to the electrical appliance.

The second way of looking at the electric circuit uses the concepts of potential differences (p. d.) or voltage (V), current (i) and resistance (R). In this case, a more differentiated description is necessary. The battery may be regarded as a device which maintains a p. d. across the two poles. As long as the internal resistance of the battery is neclected the p. d. across the poles remains constant, that means the p. d. is independent from a large current, from a small current or from no current in the circuit.

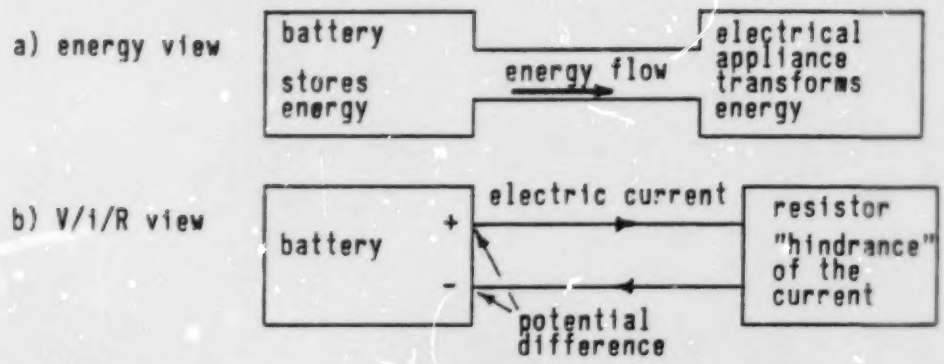


Fig. 1 Two different views of the electric circuit

The current i describes the rate of flow of electrons through the circuit ($i = dq/dt$). The current is the same for all cross sections of a circuit. This important constraint is connected to the conservation of charges which don't pile up in or drain away from any point in the circuit. For a battery with a certain p. d. the current i is a function of the resistance R. On a microscopic scale the resistance can be understood through collisions of the electrons with the lattice which hinder the flow of electrons. The resistance acts on the current everywhere in the circuit and not just "after" the resistor.

The two views of the circuit are connected with each other in the following way. The energy passes through the fields outsides the wires and flows into the resistor where Joule heat is produced. The energy flow dE/dt into the resistor is given by the product $V\,i$, which means current and voltage determine the energy flow. The two flows, the energy flow and the flow of electrons, should be distinguished carefully. While the first is unidirectional the second circulates.

3. The semantic information of the students' concepts current, voltage and resistance, and the students' energy view

It comes as no surprise that the student uses the words current and voltage differently before instruction from how the physicist uses them. Before instruction, current is a student concept which shows at least two features which are not included in the physical concept of current: The "current" may be stored in a battery or a wire as a static current, and the current may be consumed in a bulb or in another electrical appliance (Maichle, 1979, 1981, Osborne and Gilbert, 1980, Rhöneck, 1980, 1981). These aspects of the

students' concept of current are easily to be understood as a result of the strong relation between current and energy. Some students describe current as "energy" and a high percentage of students accept a similar statement (Rhöneck, 1981). In addition, nearly 50 % of a sample of German students (grade 6) quoted the word current when confronted with the word energy and when asked for their assoziations (Duit, 1982).

Taking the hypothesis of a strong relation between current and energy for granted the question arises whether or not students' concepts of resistance and voltage exist. Most of the students seem to relate a bulb to a consumption and not to a hindrance of the current. Also, to a majority of students the word resistance in connection with a bulb is not familiar (Maichle, 1981, Rhöneck, 1981). The scientific correct conception that the current has the same value before and after the bulb is held by a minority of students before instruction (Osborne, 1983).

The word voltage is know to many students in the early years of secondary school. Especially, voltage seems to be related to the current. The circumscription voltage is "the force or the strength of the electric current" is used quite frequently and the student appears to rely on this definition when the voltage has to be predicted across the bare wire or the switch in a circuit (Rhöneck, 1981, Maichle, 1979).

A structure becomes visible when this semantic information of current, resistance and voltage is combined. Usually the student's view of the electric circuit is influenced by the energy view even when using the words current and voltage. In this view the battery serves as a source in which the current is stored. The current flows through the wire to the bulb and in the bulb the current is used up. The students' concept of current is marked by features which are similar to the aspects of storage, transportation and transformation of energy in physics, even though the aspect of conservation in the students' concept may be missing. The metaphor of consumption of the current stands for the energy transformation.

For many students voltage is not an independent concept as it is in physics. The strong connection between current and voltage in the preconceptions of the student may be explained by the fact that the students' energy view only needs one first order concept and that is the current. So voltage is not an essential part of this view. Since there is no other concept with which the voltage could be connected the student tends to relate

voltage and current in such a way that a future differentiation of voltage and current may be a problem.

This short description of the expected relations between the different students' concepts and an underlying basic idea of a students' energy view of the electric circuit may facilitate the understanding of the test items which are comprised in the following test.

4. The test items and some results

The tasks of the test are presented in fig. 2. The first task was utilized by Maichle, 1981, and the second task by Osborne and Gilbert, 1979. Both tasks allow the investigation of the static and kinematic aspects of the students' concept of current. Task 1 gives additional information about the meaning of voltage. Task 3 is related to the question whether the bulb is perceived as a hindrance and resistance or as a consumer of the electric current. The last task is dedicated to the relations between current and voltage on one side and the connection between current and energy on the other side.

In table 1 the results of several groups are combined. For the first two tasks the percentage of judgements and the frequency of correct answers are shown. Task 3 and task 4 are presented by the percentage of consent. The first group consisted of 113 students from a collège (comprehensive school) in Paris (grade 6), the secound to fourth group belong to a Gymnasium (grammar-school) in Ludwigsburg (grade 5, grade 7, grade 9) and the two last groups to a Realschule (technical school) near Ludwigsburg (grade 5 and grade 7). All tests were presented before students received formal school lessons in basic electricity which begin in France during grade 6 and in this part of Germany during grade 8 (Realschule) or grade 9 (Gymnasium).

The results of the tests contain additional information which may become reasonable by mapping the relations between the different concepts. This mapping may be used to distinguish between a scientific correct view and the students' energy view of the electric circuit.

school \ item	1.2.A	1.2.B	1.2.C	1.2.D	1.3.A	1.3.B	1.3.C	1.3.D	task 1 correct	2	task 1+2 correct	3.1	3.2	3.3	3.4	3.5	4.1.a	4.1.b	4.1.c	4.2.a	4.2.b
collège (AFP) (comprehensive school) Paris, grade 6 113 students	12	35	67	04	20	26	38	04	01	73	00	84	58	06	67	43	40	26	33	90	33
Gymnasium (GGL) (grammar-school) Ludwigsburg, grade 5 29 students	59	31	41	03	21	24	34	03	00	38	00	76	10	00	55	10	31	07	24	79	10
Gymnasium (GGL) Ludwigsburg, grade 7 87 students	56	58	66	01	29	33	58	06	00	80	00	82	02	08	70	13	48	13	12	84	13
Gymnasium (MGL) Ludwigsburg, grade 9 83 students	51	65	83	01	49	49	71	08	11	84	05	87	02	25	55	31	64	11	11	83	13
Realschule (RMH) (technical school) Ludwigsburg, grade 5 46 students	50	50	63	00	04	17	37	04	00	98	00	96	15	07	74	24	52	22	17	76	14
Realschule (RWB) Ludwigsburg, grade 7 82 students	65	50	83	00	29	34	73	02	01	80	01	91	13	21	68	30	61	10	12	90	15

Table 1: Percentages of judgements (task 1 and task 2) and percentages of agreement (task 3 and task 4) before instruction.

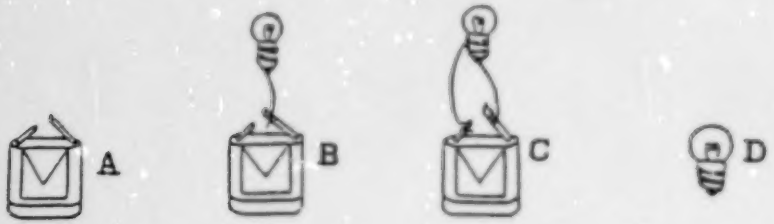
5. The concept mapping algorithm

The concept mapping serves as a representation of the different results and supports an analysis of the students' view of the electric circuit. The purpose of this analysis is to separate the students' energy view from the physicist's view of the circuit. Of course, other tasks and better tasks may be chosen to describe the so-called students' energy view, and other views of the circuit may be isolated.

In the concept mapping, resistance, current and voltage are delineated as separate concepts on one level whereas the energy concept which combines some aspects of the students' energy view is placed on another level. To begin with, the relations compatible with the students' energy view are described. These relations do not exist in physics. "The bulb consumes the current" indicates a connection between the bulb and the students' energy view although in physics the current i is constant everywhere in the circuit and cannot be consumed. The phrase "voltage and current occur always together"

(1)

Look at the four arrangements A, B, C and D.



Read each of the sentences below and put a tick in the box if you think the sentence is true. If you don't know tick off the corresponding box.

	A	B	C	D	I don't know
1. The bulb shines in figure:		☐	☐	☐	☐
2. An electric current exists in figure:	☐	☐	☐	☐	☐
3. An electric voltage exists in figure:	☐	☐	☐	☐	☐

(2)

Considering figure 2 there is no bulb in the lamp-socket. The switch is on.

	true	false	I don't know
There is an electric current in the wire leading to the lamp-socket. Decide !	☐	☐	☐

Fig. 2 Tasks to assess the semartic structure

(3)

The bulb is connected with the battery. The bulb shines. Decide in each of the following sentences !

	true	false	I don't know
1. The bulb consumes the electric current.	☐	☐	☐
2. The bulb drives the electric current.	☐	☐	☐
3. The bulb hinders the electric current.	☐	☐	☐
4. The bulb takes part of the energy of the electric current.	☐	☐	☐
5. The bulb is a resistor.	☐	☐	☐

(4)

Here you find sentences which are related to the electric current and the electric voltage. Put a tick in the corresponding box if you think the sentence is true, false or you don't know.

	true	false	I don't know
1.a. The electric voltage and the electric current occur always together.	☐	☐	☐
1.b. The electric voltage may occur without an electric current.	☐	☐	☐
1.c. The electric current may occur without an electric voltage.	☐	☐	☐
2.a. The electric current is energy.	☐	☐	☐
2.b. The electric voltage is energy.	☐	☐	☐

indicates a too strong connection between current and voltage while "the electric voltage may occur without the electric current" describes correctly the situation where a battery is not connected to an electrical appliance. "Current is energy" may be understood as an explanation of current in the students' energy view. All these statements are presented in fig. 3. a. When a student ticks off A, B and C in line 2 of task 1 (v. fig. 2) and marks task 2 as true he had been labeled as one who starts from a static electric current in the batteries and in the wires. This static electric current has an equivalent in the stored energy in the students' energy view but not in the scientific concept of current. Another incorrect strategy is to tick off current and voltage in the same way. These two distinctive strategies are represented in fig. 3. a. by waved lines.

When the student answers the questions correctly other relations emerge between current, voltage and resistance. Only the statement "the bulb hinders the electric current" is included in fig. 3. b. In addition, the correct use of the concepts current and voltage in task 1 and task 2 and the solution of these tasks is marked in fig. 3. b.

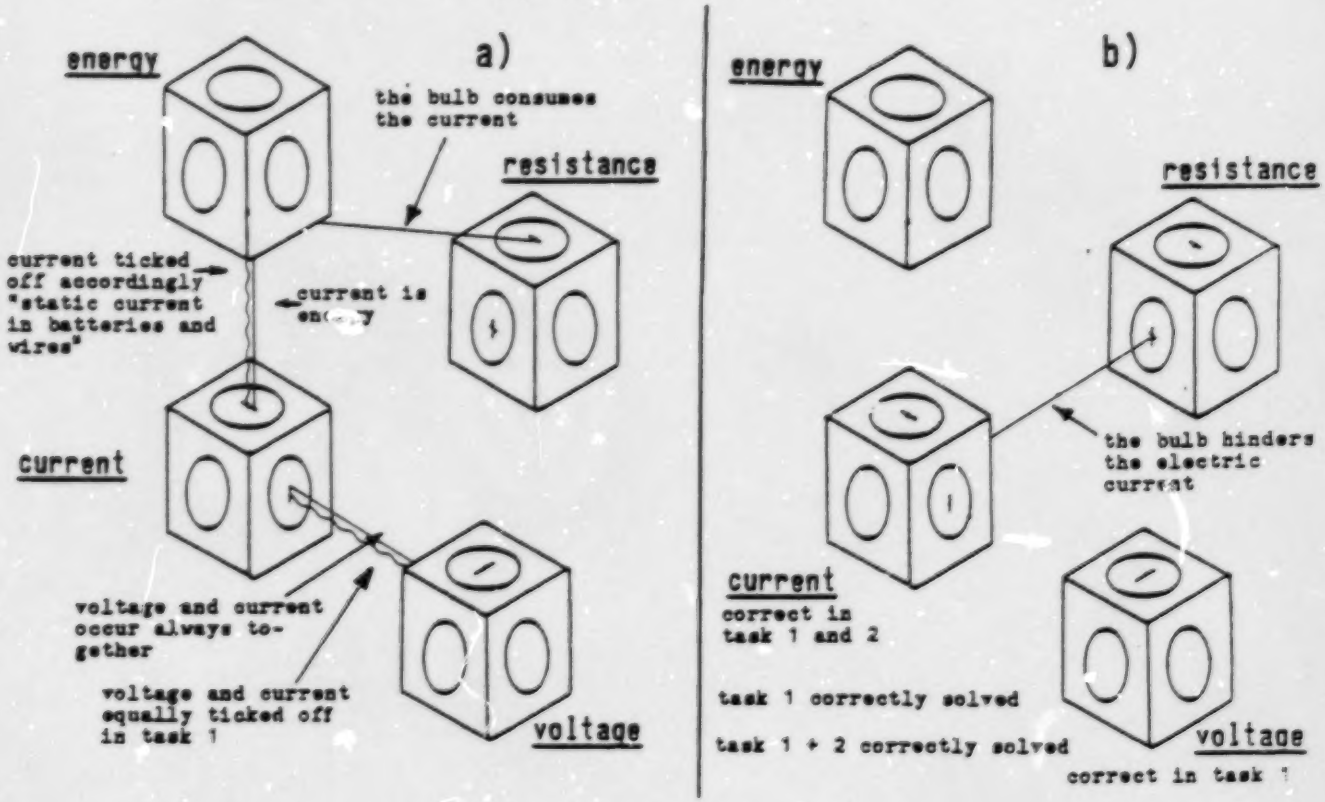


Fig. 3 a) statements compatible with the students' energy view b) correct results compatible with the V/i/R view

6. Description of student concepts before instruction

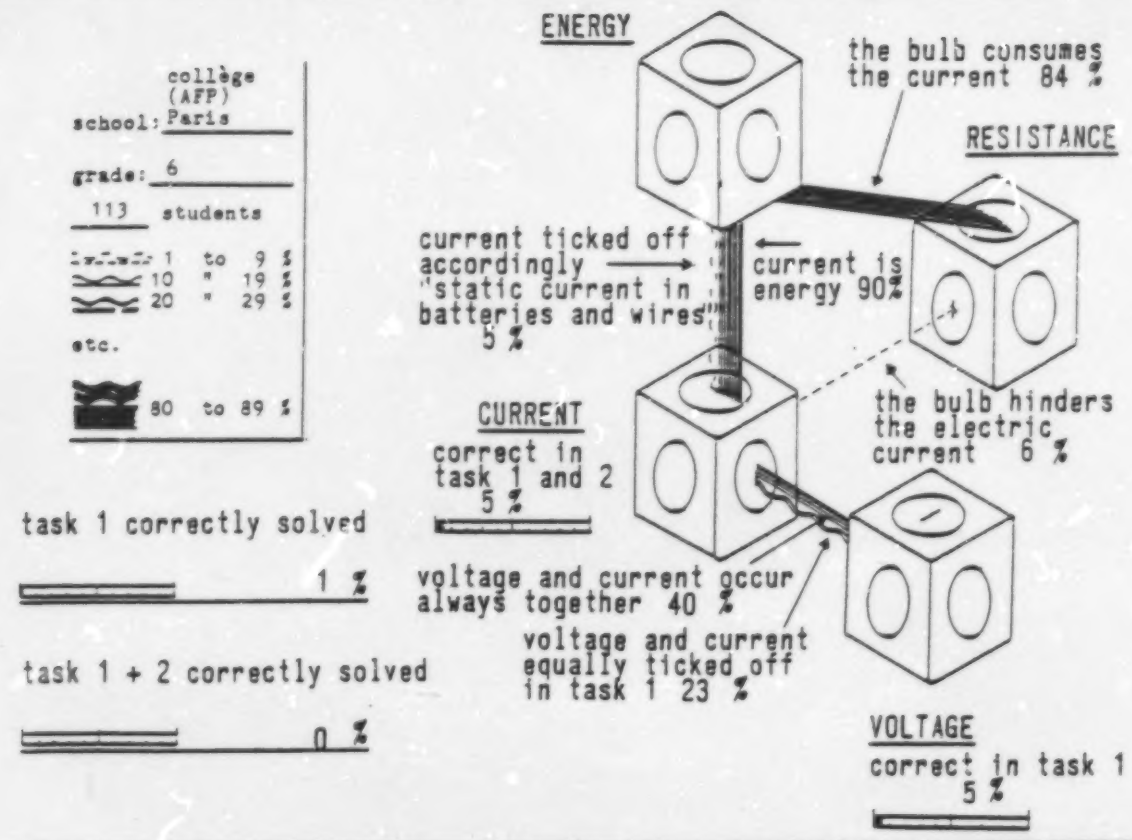
For a group of students, when all information contained in fig. 3.a and b is combined in one figure a synopsis of the two views is obtained. Fig. 4 and fig. 5 present the combined concept mappings of some of the results shown in tab.1. The number of connections between the different concepts corresponds to the percentage of relations in the group.

As fig. 4 and fig. 5 show the relations compatible with the students' energy view are much stronger than the agreement with the correct V/i/R view. The two mappings of fig. 4 with the results of a French school (grade 6) and a German Gymnasium (grade 5) resemble each other. Only a more detailed analysis would show a strong tendency of the French students to tick off line 2 of task 1 correctly while the German students tend to solve this item with a more static concept of current. This discrepancy is not shown in fig. 4 because both groups mainly solve task 2 with a static current. The corresponding waved line in fig. 4 combines the strategies to solve task 1 and task 2.

The rather delated beginning of instruction in basic electricity in the German schools enables to follow the development of the semantic structure prior to a formal teaching (v. fig. 5). When the students grow older the false strategies represented by waved lines increase (v. fig. 4 and fig. 5). Between grade 5 and grade 9 the developing strategies are recorded better and better by the tasks.

Immediately before instruction 11 per cent of the students (Gymnasium, grade 9) are solving task 1 correctly. The corresponding concept mapping of this special group is given in fig. 5. b. Noticeably, the concept mapping of these students is nearly identical with the mapping of all students in the group with the exception of the strategies to solve task 1 and task 2. This fact may be explained in the following way. The students solving task 1 correctly may use the information that voltage describes a battery and that current is mainly a kinematic concept. However, the rest of the semantic structure may be influenced by the energy view as in the whole group.

An intensely discussed question is how stable is the semantic structure described by the concept mapping. In all cases, the figures 4 and 5 show a predominancy of relations which are not included in a scientific correct view of the electric circuit. However, the agreement with a single


collège (AFP)
school: Paris
grade: 6
113 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
1 %
task 1 + 2 correctly solved
0 %
ENERGY
the bulb consumes the current 84 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 5 %
current is energy 90%
the bulb hinders the electric current 6 %
CURRENT
correct in task 1 and 2 5 %
voltage and current occur always together 40 %
voltage and current equally ticked off in task 1 23 %
VOLTAGE
correct in task 1 5 %

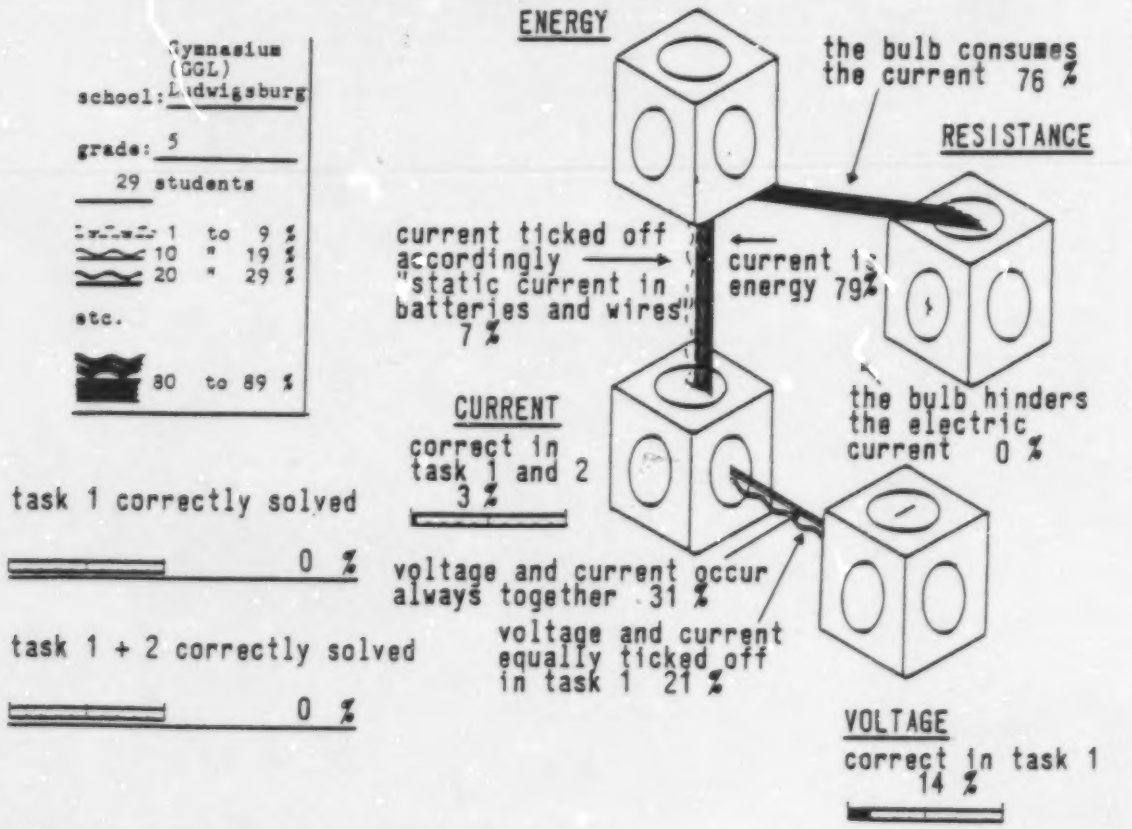

Gymnasium (GGL)
school: Ludwigsburg
grade: 5
29 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
0 %
task 1 + 2 correctly solved
0 %
ENERGY
the bulb consumes the current 76 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 7 %
current is energy 79%
the bulb hinders the electric current 0 %
CURRENT
correct in task 1 and 2 3 %
voltage and current occur always together 31 %
voltage and current equally ticked off in task 1 21 %
VOLTAGE
correct in task 1 14 %

Fig. 4 Concept mapping before instruction

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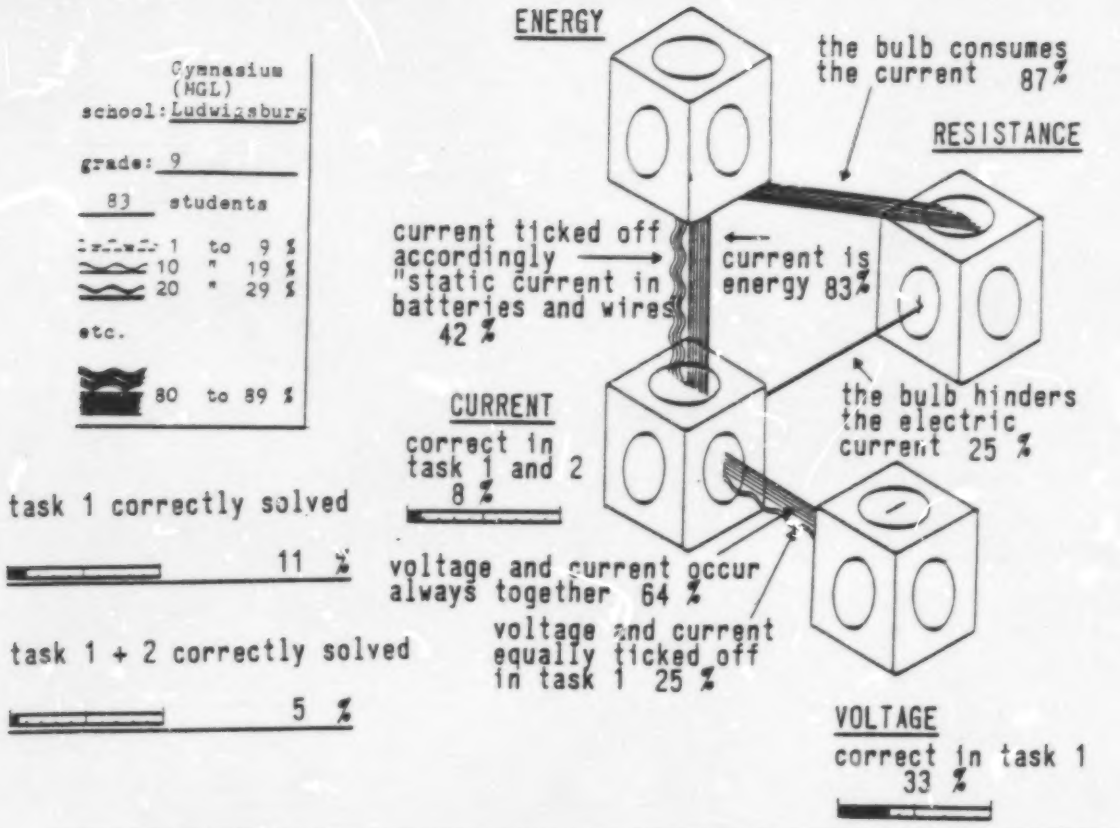
Gymnasium (MGL)
school: Ludwigsburg
grade: 9
83 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
11 %
task 1 + 2 correctly solved
5 %
ENERGY
the bulb consumes the current 87%
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 42 %
current is energy 83%
the bulb hinders the electric current 25 %
CURRENT
correct in task 1 and 2 8 %
voltage and current occur always together 64 %
voltage and current equally ticked off in task 1 25 %
VOLTAGE
correct in task 1 33 %

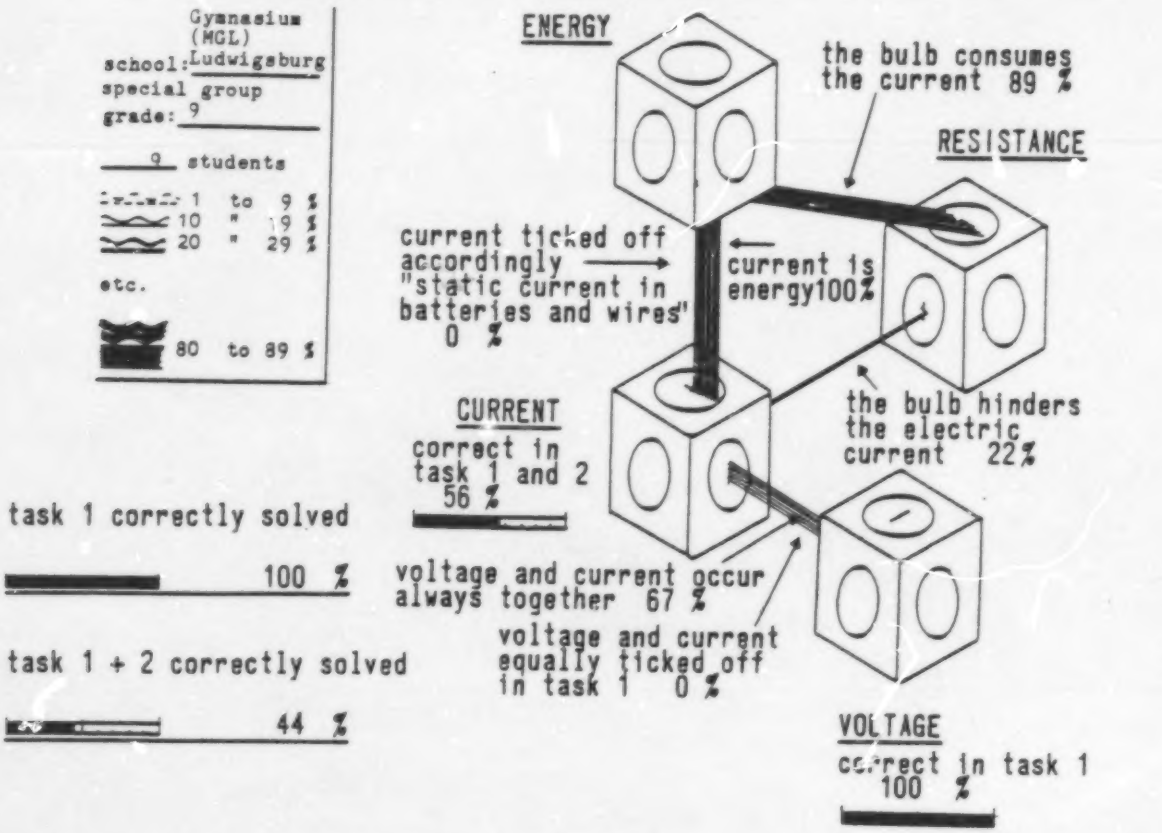
Gymnasium (MGL)
school: Ludwigsburg
special group
grade: 9
9 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
100 %
task 1 + 2 correctly solved
44 %
ENERGY
the bulb consumes the current 89 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 0 %
current is energy100%
the bulb hinders the electric current 22%
CURRENT
correct in task 1 and 2 56 %
voltage and current occur always together 67 %
voltage and current equally ticked off in task 1 0 %
VOLTAGE
correct in task 1 100 %

Fig. 5 Concept mapping before instruction

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"false" statement or a certain incorrect strategy is not 100 per cent and has no dogmatic quality. This partial vagueness of the items may be explained by broad students' concepts which do not exclude the correct semantic structures nor the semantic structures typical for the students' energy view. In any case, relations are recorded before instructions which do not harmonize with the semantic structures in physics.

When the same test is presented twice to a student some disagreements are found (fig. 6). For example, when a student uses the static aspect of current to solve task 1, three weeks later he may use the kinematic aspect because both aspects are acceptable to him. When he initially agrees with "current is energy" he may disagree later with the restriction "current is electricity". In case of re-testing three classes every eighth tick changed in grade 7 from "false" to "correct" or vice versa, every ninth tick in grade 8, and every seventh tick in grade 9 (v. fig. 6). It should be noted that the corresponding mapping for successive tests in the same group does not show considerable changes.

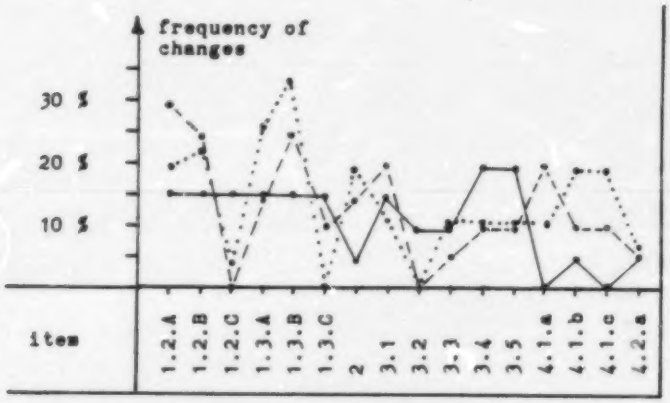


Fig. 6 Changes from "false" to "correct" and vice versa in two identical tests before instruction
_____ grade 7 (Realschule) ------ grade 8 (Realschule)
..... grade 9 (Gymnasium).
span between the two tests: 2 to 6 weeks

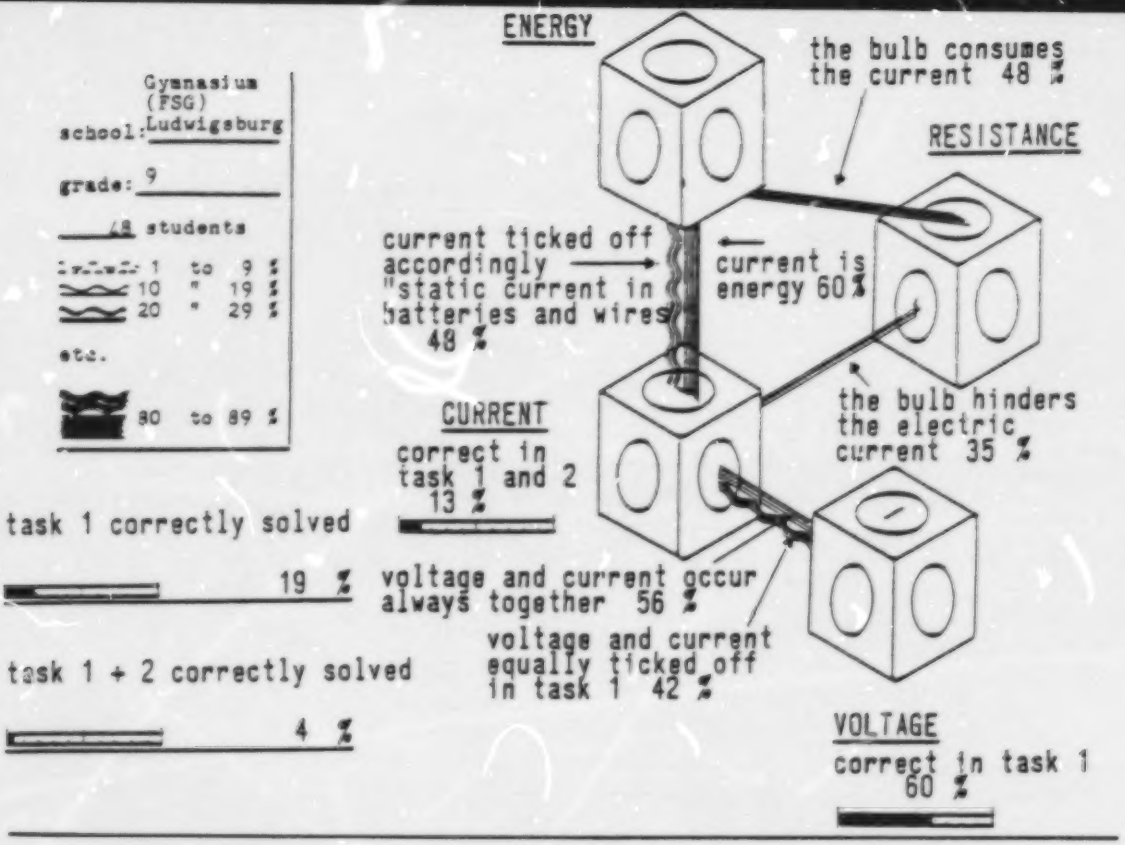
7. The concept mapping after instruction

The semantic structures obtained with the same methods after a first period of instruction usually do not show the expected changes. The tasks presented to the students contained some additional questions in task 1, 2 and 4 which cannot be translated because there is no distinction between current and i = dq/dt in English as it is in the French and German language (i = l'intensité du courant, i = Stromstärke). In the following, the restricted results are discussed where only the term current is included.

The concept mapping of the results of selected groups is presented in fig. 7, 8 and 9. Figure 7 shows the outcomes of a school in Paris (grade 9) several month after instruction and the results of a gymnasium (grade 9) in Ludwigsburg 4 weeks after instruction. In both cases a distinction between an energy view and the V/i/R view of the circuit was not explicitly taught. The most striking result is the rather small difference between the concept mappings before and after instruction. (v. fig. 4, 5a and 7). When the different views are not explicitly taught the students' energy view generally resists the period of instruction. In addition, the incorrect strategies seem to develop from grade 5 to grade 9 with instruction as well as without instruction.

Fig. 8 shows the concept mapping of two groups (Realschule) which were especially taught. The first of these groups was instructed with a particular emphasis on the concept of voltage. This objective was accomplished to a sufficient extent, as additional tasks could show, but the mapping did not reflect a change in the view of the electric circuit. Discussions on the level of concepts seems not to be a promising strategy when the change of the view is intended. We were especially disappointed with the finding that the strong relation between current and voltage was not weakened (see fig. 8a). The new concept of voltage seems to be embodied in the students' view of the circuit. In this regard the results of fig. 8b are much better. Here the energy view and the V/i/R view were explicitly discussed and the mapping indicates some changes in the correct direction.

The concept mapping of the first attempt to distinguish between the different views in a Gymnasium is shown in fig. 9. In this case, the mapping records good results directly after instruction (fig. 9a) and rather good results four month later. Task 1 and task 2 are often solved correctly. Current and voltage seem to be discriminated, but the statement "current is energy" is not negated as we expected it to be.


Gymnasium (FSG)
school: Ludwigsburg
grade: 9
48 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
19 %
task 1 + 2 correctly solved
4 %
ENERGY
the bulb consumes the current 48 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires 48 %
current is energy 60 %
the bulb hinders the electric current 35 %
CURRENT
correct in task 1 and 2 13 %
voltage and current occur always together 56 %
voltage and current equally ticked off in task 1 42 %
VOLTAGE
correct in task 1 60 %

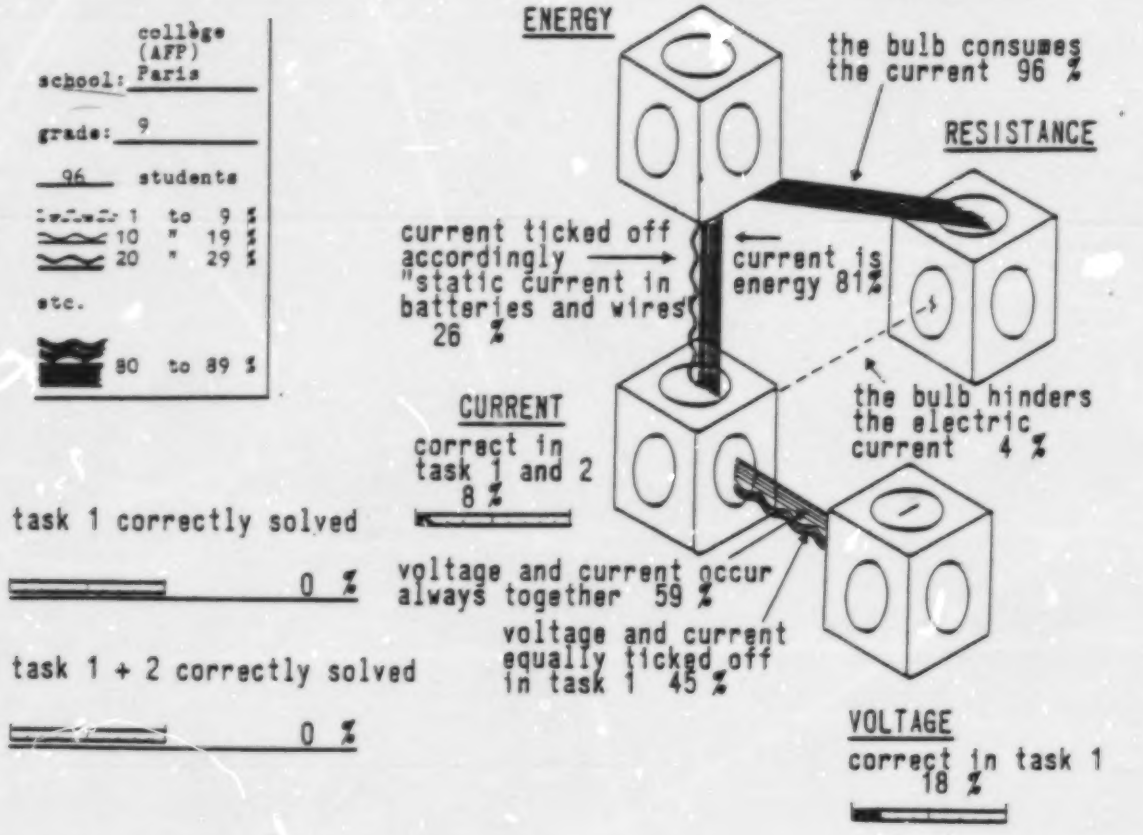

college (AFP)
school: Paris
grade: 9
96 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
0 %
task 1 + 2 correctly solved
0 %
ENERGY
the bulb consumes the current 96 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires 26 %
current is energy 81 %
the bulb hinders the electric current 4 %
CURRENT
correct in task 1 and 2 8 %
voltage and current occur always together 59 %
voltage and current equally ticked off in task 1 45 %
VOLTAGE
correct in task 1 18 %

Fig. 7 Concept mapping after instruction

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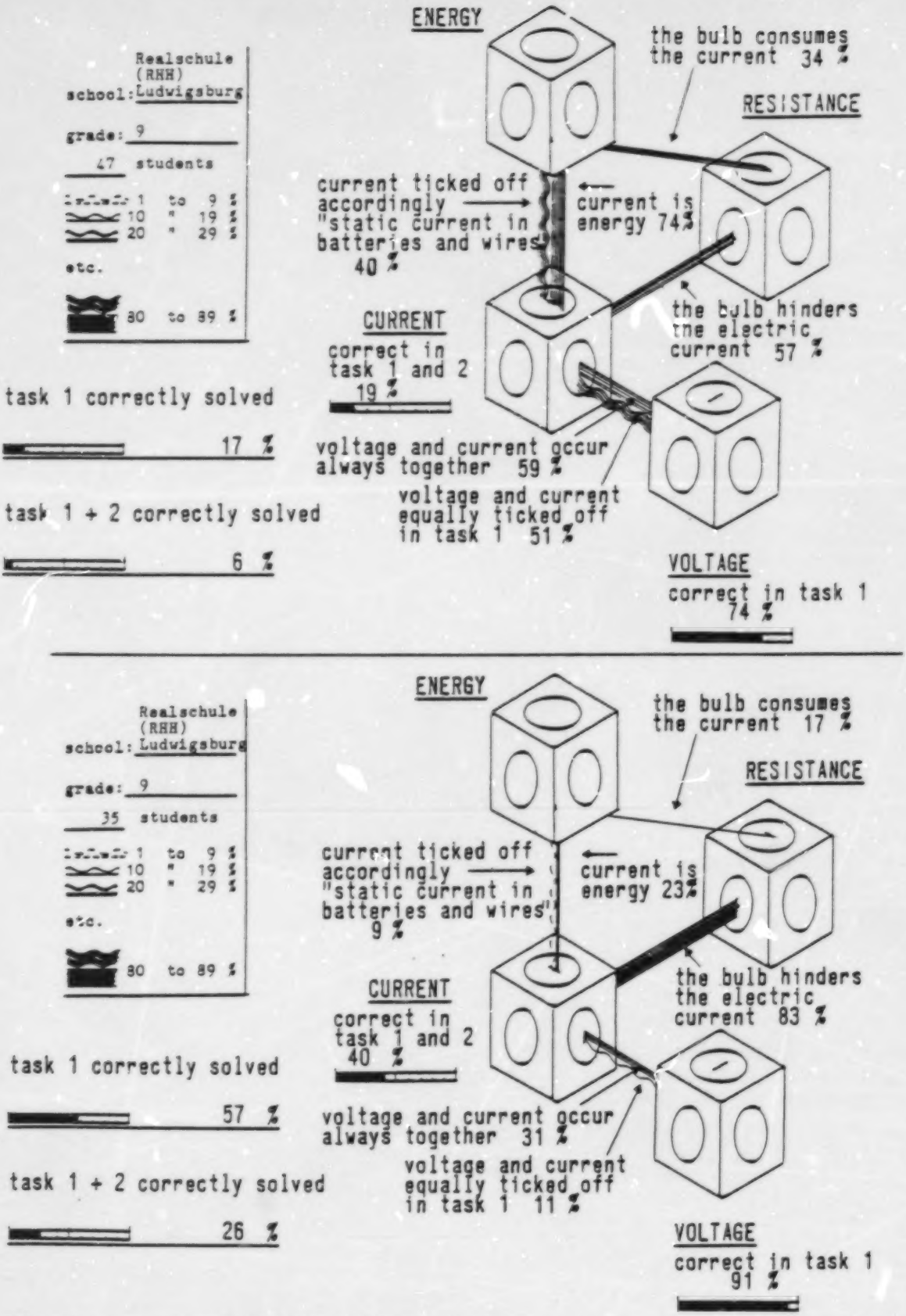
Realschule (RHH)
school: Ludwigsburg
grade: 9
47 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
17 %
task 1 + 2 correctly solved
6 %
ENERGY
the bulb consumes the current 34 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 40 %
current is energy 74 %
the bulb hinders the electric current 57 %
CURRENT
correct in task 1 and 2 19 %
voltage and current occur always together 59 %
voltage and current equally ticked off in task 1 51 %
VOLTAGE
correct in task 1 74 %
Realschule (RHH)
school: Ludwigsburg
grade: 9
35 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
57 %
task 1 + 2 correctly solved
26 %
ENERGY
the bulb consumes the current 17 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 9 %
current is energy 23 %
the bulb hinders the electric current 83 %
CURRENT
correct in task 1 and 2 40 %
voltage and current occur always together 31 %
voltage and current equally ticked off in task 1 11 %
VOLTAGE
correct in task 1 91 %

Fig. 8 Concept mapping after instruction

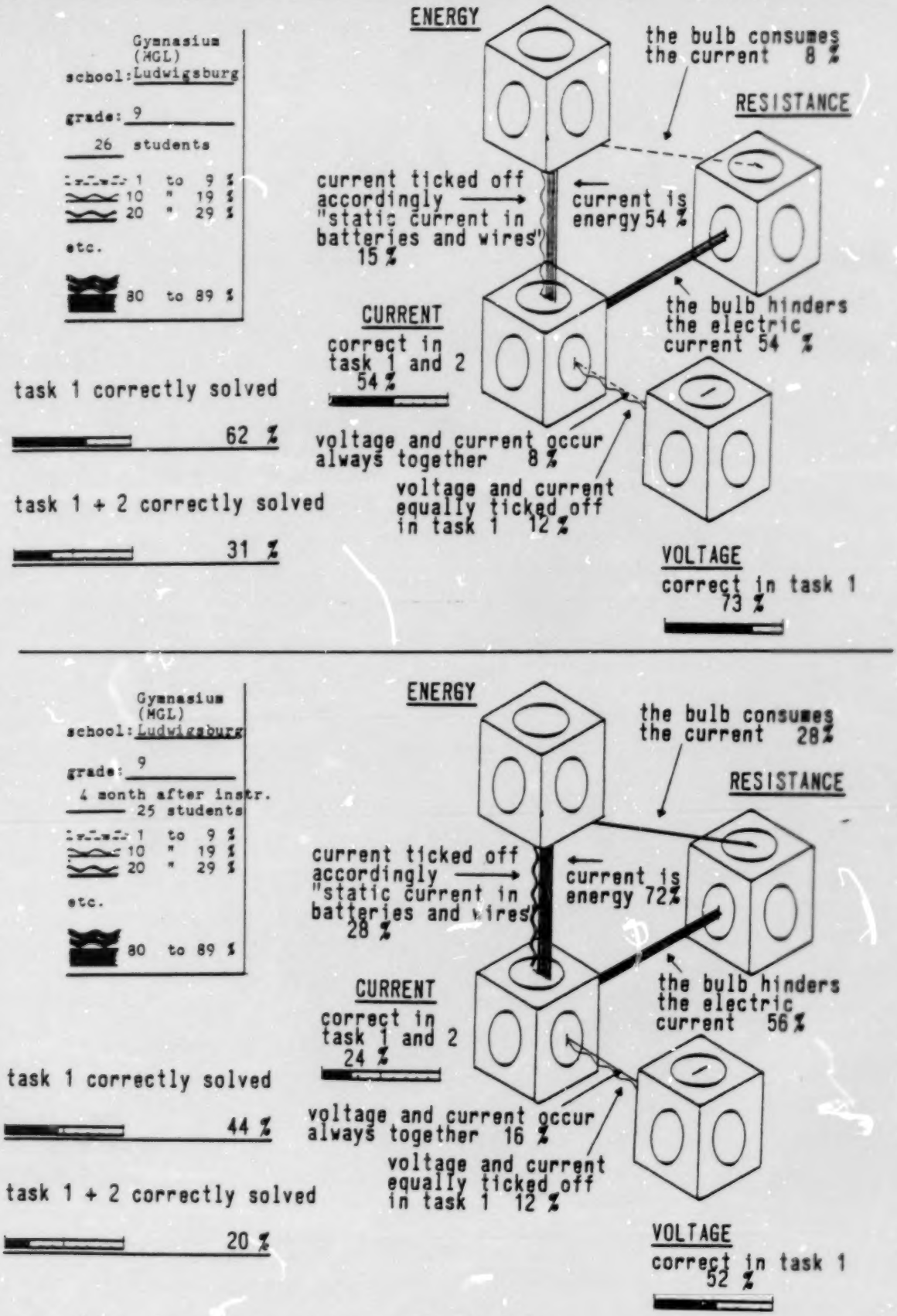
Gymnasium (MGL)
school: Ludwigsburg
grade: 9
26 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
62 %
task 1 + 2 correctly solved
31 %
ENERGY
the bulb consumes the current 8 %
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 15 %
current is energy 54 %
the bulb hinders the electric current 54 %
CURRENT
correct in task 1 and 2 54 %
voltage and current occur always together 8 %
voltage and current equally ticked off in task 1 12 %
VOLTAGE
correct in task 1 73 %
Gymnasium (MGL)
school: Ludwigsburg
grade: 9
4 month after instr.
25 students
1 to 9 %
10 " 19 %
20 " 29 %
etc.
80 to 89 %
task 1 correctly solved
44 %
task 1 + 2 correctly solved
20 %
ENERGY
the bulb consumes the current 28%
RESISTANCE
current ticked off accordingly "static current in batteries and wires" 28 %
current is energy 72%
the bulb hinders the electric current 56%
CURRENT
correct in task 1 and 2 24 %
voltage and current occur always together 16 %
voltage and current equally ticked off in task 1 12 %
VOLTAGE
correct in task 1 52 %

Fig. 9 Concept mapping after instruction

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The results discussed so far indicate the students' difficulties to differentiate the energy view and the V/i/R view of the electric circuit as they are used in physics. These views should be taught explicitly and in multiple situations during instruction (Härtel, 1982). The teacher should be aware of the necessity to present information on single concepts and their relations as well as on mental structures and views. In fig. 10 the level of concepts contrasts with the level of structures. The arrows indicate the transitions between the different elements of a teaching unit underlying the results presented in fig. 8b. A detailed discussion of fig. 10 exceeds the purpose of this paper.

The discussion of the views of the circuit is a very difficult task for the teacher. But this task may become easier when the semantic structures which disturb the process of learning are indentified. A certain change of the semantic structures seems to be possible when the different views and the various concepts are described appropriately. Perhaps, the increase of an understanding of the simple electric circuit leads to a better performance when more complicated circuits (Closset, 1983, Shipstone, 1982), circuit diagrams (Fredette and Clement, 1980, Joshua, 1982) and more complex problems (Riley et al., 1981, Caillot and Chalouhi, 1983) are presented.

8. The importance of preconceptions in cognitive conflicts

The manipulatory analysis of simple electric circuits, additional interviews, and the concept mapping of the semantic structures lead to converging descriptions of the students' preconceptions regarding electric phenomena. Tiberghien and Delacôte, 1976, emphasize a linear causal effect between batteries and bulbs, that means the battery acts on the bulb. Fredette and Lochhead, 1980, use a sink model to describe the students conceptions. Andersson, 1980, points out the source-consumer model for electric circuits. Maichle, 1982, uses a give-schema to analyze the processes in a circuit. Finally, in this paper the semantic structures are interpreted on the basis of a socalled students' energy view where current and energy flow are intermixed. Common to all of these studies is a one-dimensional description of the processes in a circuit. The term 'one-dimensional' will become clear in the next section.

The outcomes of the research work on representation should improve the design of instruction. One component in search of better teaching methods could be to define such situations which are incompatible with the student's preconceptions. In this way conflicts may be produced between prospective

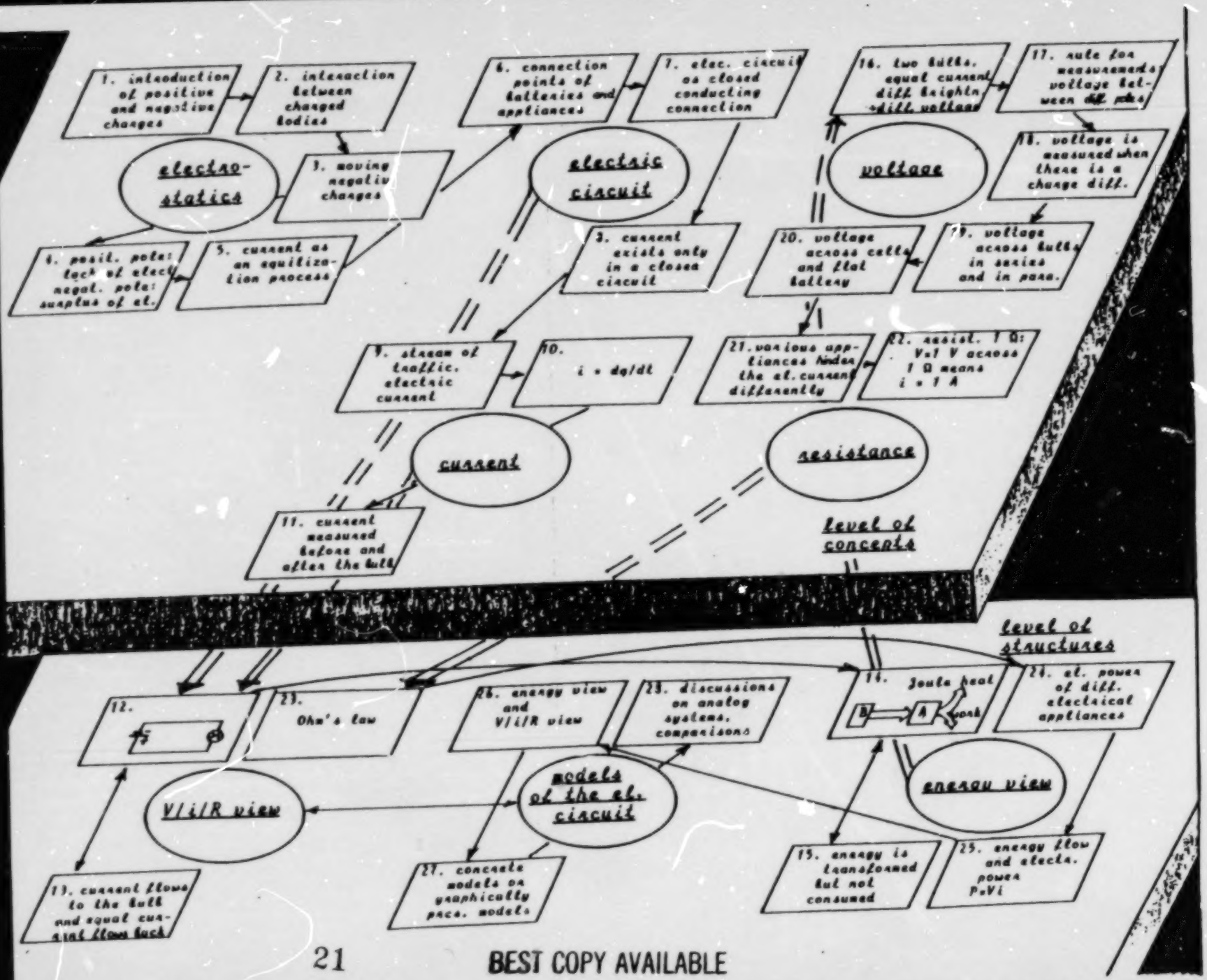
1. introduction of positive and negative charges
2. interaction between charged bodies
3. moving negativ charges
4. posit. pole: lack of elect. negat. pole: surplus of el.
5. current as an equilization process
electro-statics
6. connection points of batteries and appliances
7. elec. circuit as closed conducting connection
electric circuit
8. current exists only in a closed circuit
9. stream of traffic. electric current
10. i = dq/dt
11. current measured before and after the bulb
current
16. two bulbs, equal current diff brights diff voltage
17. rule for measurements voltage between diff poles
18. voltage is measured when there is a charge diff.
voltage
20. voltage across cells and flat battery
19. voltage across bulbs in series and in para.
21. various appliances hinder the el. current differently
22. resist. 1 Ω: V=1 V across 1 Ω means i = 1 A
resistance
level of concepts
level of structures
12.
13. current flows to the bulb and equal current flow back
23. Ohm's law
V/i/R view
26. energy view and V/i/R view
25. discussions on analog systems, comparisons
models of the el. circuit
27. concrete models or graphically para. models
14. Joule heat
heat
24. el. power of diff. electrical appliances
energy view
15. energy is transformed but not consumed
25. energy flow and electr. power p=Vi

Fig. 10 Teaching sequence on the level of concepts and on the level of structures

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learning materials and the student's preconceptions. These conflicts could be used to analyze the argumentation which usually hinders the development of a more adequate knowledge structure. As expected, the primitive conceptions tend to assimilate the incoming information. This may be illustrated when the student has been exposed to i=const (v. next section). The constraint i=const should be incompatible with the abovementioned conceptions. But the conservation of current is accepted on condition that the student introduces a second variable. This second variable describes a property of the electric current and is related to the student's idea of voltage.

9. The conflict between i=const and the explanation of a used battery

In order to study a conflict between the student's preconceptions and the constraint i=const some students were interviewed. In total 15 students of grade 9 in a "Gymnasium" (grammar-school) participated. These interviews were carried out prior to a first period of instruction. The dialoque began with the questions how to make an empty electric torch without batteries work and what happens when the torch is switched on. This introductory discussion should show which terms were used spontaneously by the students. All students but one used the term current to describe the processes in the electric torch.

Then the student was asked to describe the current in a circuit with one bulb and two round cells in series (see fig. 11). All students had already formed an idea of the current in the circuit. Primitive ideas with unidirectional currents and more sophisticated models with circulating currents were used. After the student predicted for example a current from the positive pole to the battery the current was measured with an ammeter. Afterwards the ammeter was used to demonstrate i=const subsequent to the predictions of the student what will happen in the second wire and between the two round cells.

During the interview the students were confronted with the conflict between their predictions and the reading of the ammeter. The difference between the students' concept of current and the current measured by the ammeter was part of this conflict. Since i=const was accepted the students were subsequently asked to answer the following question: When the current goes round and the current is unchanged what is meant by "the battery becomes unusable"?

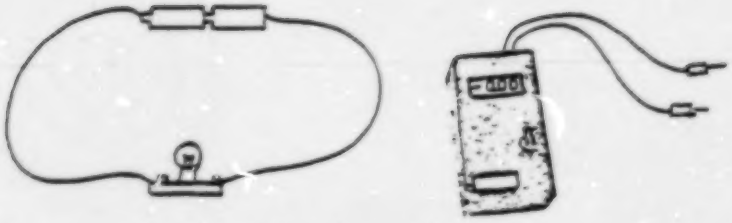


Fig. 11 The circuit used in the interview

In the following, some selected excerpts of the interviews are quoted. The first excerpt rather demonstrates a primitive picture.

Vi (Vi said that two currents meet in the bulb:)

I: Does a current flow in the battery?

S: No, the current is stored up in the battery.

I: (After demonstrating i=const in the battery:) Could you explain why even in the battery a current flows?

S: There are molecules or something else in there and I believe, that this ... (uncertain remark)

I: Is it possible that the current goes this way and the opposite way as well to the bulb after we have measured an unchanged current before, after, and in the battery?

S: Yes, that's possible.

I: How does it work?

S: Oh, I do not know, I have no idea.

I: The current does not flow this way. Has "electric circuit" ever been explained to you?

S: Yes, but I was never concerned with it.

I: Namely, that is to say the current flows in a circuit and flows trough the battery. Please, could you answer me some additional difficult questions? When the current goes round and the current is unchanged in all parts of the circuit what does it mean to you "the battery becomes unusable"?

S: Though the circuit is closed the current looses more and more its force. That happens a million times in the circuit.

I: Where does the current loose its force?

S: In the bulb, there it is consumed.

First of all, the student comes to a point where a second variable is introduced. This second variable appears as a property of the electric current in the paraphrase "force of the current". This force of the current often reappears in the circumscriptions of the student's concept of voltage before and after instruction.

In the next interview another solution becomes visible. In this case the student introduces a second variable, too.

Co (The student decided on clashing currents after the demonstration of i=const before and after the bulb:)

I: Does a current flow in the battery?

S: No, a current through the battery, that's impossible.
(After the demonstration of i=const in the battery the student laughs and says:) The old batteries are empty, therefore the current has to leave. Perhaps less current goes back or nothing comes back to the battery.

I: How does it work when the current is the same in the battery, before, and after the bulb?

S: Perhaps with the pressure, I really don't know.

I: And what happens when the battery is used up?

S: When the current is not so strong, perhaps the bulb shines less bright, perhaps the current was pressed in the battery. The current goes through the wire and afterwards the pressure decreases.

I: What means the battery is used up?

S: The battery has no more pressure and there is no more current in there, the current is used up.

I: Even though the total current flows back as we have seen?

S: Yes, but the energy ...!
The energy is used up. What I mean is: I am able to run and when I am exhausted the energy is lost.

When confronted with i=const the student uses the pressure produced in a battery as a second variable. In this picture the second variable is not a property of the electric current. At least the student does not use the word pressure in a minor function. This interview is remarkable for a second reason. The energetic aspect of the student's concept of current becomes evident in the last section of the interview, where the student explicitely equates current and energy.

In these two interviews the students did not spontaneously refer to circulating currents and circuits. In the following, the students make use of circulating currents. To begin with, an excerpt will be discussed where the student combines the circuit with the consumption of current.

Ge (Ge pointed out that the current flows in a circuit:)

I: Does a current also flow in the battery?

S: Yes, the current flows through the battery.

I: How much current flows in the battery?

S: As much as in the wires.

I: When the current goes round and the current is unchanged what is meant by "the battery becomes unusable"?

S: The current is consumed very slowly. The bulb would not shine when the current could not flow through the bulb. In course of time so much current is consumed that it can not be delivered in the same way and the bulb shines with less brightness.

I: When the battery gets back the total current, why does the battery become empty?

S: In any case there is a loss. A minimal loss but it becomes apparent after some time. And the voltage decreases.

I: Now, you use the term voltage.

S: Voltage is the strength of the current. The voltage in a transmission line has more strength than the voltage in a battery. There is a difference between electrical devices which consume more or less.

I: What happens to the voltage when you go around the circuit?

S: Even the voltage stays the same.

This student combines i=const and the consumption of current. The student begins with the statement i=const. Only the hint at the unusable battery provokes the idea of a consumed current. Via a "minimal loss" the constraint i=const and the consumption come to be nearly compatible. In total three students out of 15 students searched for a compromise like this. In the above-mentioned interview the student introduces the term voltage, too. Voltage as a second variable regulates the "strength" of the current. Beyond that the same rule "stays the same" applies to current and to voltage. Voltage and current are closely associated.

The next student already works with a circulating current and i=const.

U1 (U1 uses the electric circuit)

I: Does a current flow in the battery, too?

S: Yes, here are two batteries in series and the current flows from the last round cell into the first.

I: Is there a difference between the currents before and in the middle of the two cells?

S: No, the current remains the same.

(After demonstrating i=const between the two cells:)

I: When the current circulates and the current is unchanged what does it mean to you "the battery becomes unusable"?

S: The current flows from the positive pole to the bulb. There the current is transformed into light and afterwards the current must flow to some place, that is why the current flows back.

I: You say the current is transformed into light. Does that mean less current flows back? (No reaction.)

We have seen the same current flowing back. Therefore the battery never should become empty.

S: It is possible that after a while the current decreases from 0.09 to 0.06 and on this account the bulb becomes darker.

I: Can you explain why the battery becomes empty when the entire current flows back?

S: The current is worn out.

I: What does happen in the bulb?

S: The bulb concumes a little bit and the used current flows back.

I: How does it work?

S: In a transmission line the current is sent away with many volts. Less volts arrive at the plug. On the way the volts are lost. In this case it is the same.

When this student talks about a consumption of current the aspect of devaluation and not the aspect of diminuation seems to dominate. In this way i=const becomes understandable and the devaluation of the current is associated with the volts which may be lost. The voltage is described explicitly as strength of the current.

The following interview shows that i=const may be accepted without restriction. The current is seen as constant around the circuit and the consumption of voltage descibes the energetic aspect:

Ra (Ra uses the concept of circulating currents:)

I: Does a current flow in the battery?

S: Yes, the current is the same everywhere.

I: (After demonstrating i=const in the battery:) When the current circulates and the current does not change what does it mean to you "the battery becomes unusable"?

S: I mean the electrons are slowed down and then the current decreases. In the circuit are teeming electrons, the first electron knocks against the next electron and the electrons go round. Some time the electrons are not so fast and the bulb dims.

I: What is the reason for the slow-down of the electrons?

S: For example there is friction and some heat is given to the wire. When the current increases very much the wire becomes hot.

I: A little while ago (in the first part of the interview) you used a second term, voltage. Please tell me what is voltage?

S: Voltage means how many volts come from a battery or another source. In this case we have 3 volts. Before the bulb are 3 volts and after the bulb are zero volts because the voltage is consumed.

This student is acquainted with i=const and his description of the energy flow is compatible with the invariability of the electric current. His explanation of the energy flow is simple: The second variable, voltage, is used for this purpose.

The quoted excerpts of the interviews contain a changing and a static element. Obviously, a development from an unidirectional current to a circulating current is possible. The students accept the corresponding energetic questions. But the solution of the energetic problems reach only a certain level which represents a rather primitive picture: The student tends to introduce a second variable when confronted with i=const and when asked for an explanation of the used battery. This second variable frequently is defined and described as voltage, strength of the current, or force of the current. In this way before instruction the second variable and the concept of voltage are predetermined to a certain extent. Strictly speaking the primitive <u>one-dimensional</u> view is preserved. Hence it follows that special efforts will be necessary to come to a multi-dimensional description including an independent concept of voltage.

The preconceptions seem to be rather resistent even to cognitive conflicts. The broad and vage students' concepts allow a multitude of explanations within the students' primitive views. The development of the naive preconceptions to a simplified scientific theory could begin with a certain desequilibrium produced by cognitive conflicts. But essential additional information

seems to be necessary to change the preconceptions of the student.

Do we know what is an essential additional information? Part of this information could be the bicycle chain model for i=const, comments on the distincion between current and energy, or the emphasis of an independent voltage concept. In this way a multi-dimensional description may be promoted which is necessary for an understanding of basic electricity and for problem-solving in this domain.

10. The introduction of voltage

The introduction of the concept of voltage in grade 8 or 9 is difficult for several reasons. First of all, the preconceptions of the student should be mentioned.

Secondly, the problem arises in which way the concept of voltage should be introduced. The students are acquainted neither with electric fields nor with the concept of potential difference. So a formally correct definition appears to be impracticable.

Thirdly, the necessary circumscription of voltage should enable the student to predict voltages in simple problems and to handle a voltmeter. The preliminary circumscription of voltage should be improvable in later teaching sequences.

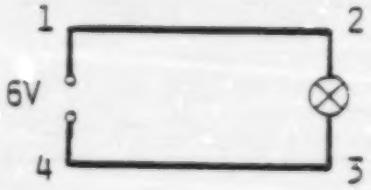
Some short remarks may be allowed on the circumscription of voltage. In many textbooks voltage is described as the drive of the electric current. This means that something is moving in the circuit, and this something does not move without a drive of a battery or another source. Besides this meaning the word "drive" has a considerable dynamic aspect. But voltage in physics is not a force, it is a potential difference.

The necessary revised information on voltage may be introduced in different ways. Sometimes voltage is described as the amount of energy given to a single electron per charge of the electron ($V = W/q$). This energy is delivered to the electron in the battery and given to the lattice in the resistance. Such a definition results in difficulties when for example the energy transfer in more complicated circuits should be explained to the student. An alternative approach may be started with measuring the voltages across the battery, the wires, the switch, and the bulb in a circuit. These activities serve to break the strong connection between voltage and current. Following these measurements, the student may be able to find a rule on his own: A voltage is measured when the measurement device is connected with plus

and minus. Provided that the teacher previously explained the poles of the battery with the lack and the surplus of electrons this rule may be improved: In a circuit a voltage is only measured when a charge difference exists. In this primitive model the battery is a device that constantly maintains a charge difference across the poles no matter what current flows. The charge difference stands for the abstract potential difference and "causes" the current in a circuit. It should be noted that charge differences are actually necessary in a circuit. They are found on the surface of the conductors and are producing the electric field inside the wires that makes the electrons run (v. Walz, 1982). When these effects are discussed during a later period of instruction the picture of charge differences on the surface may be extended.

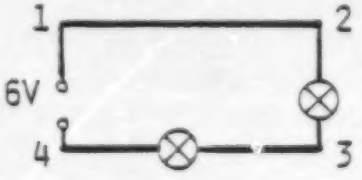
The circumscription of voltage as a charge difference enables the student to use simple operating rules when voltages are to be predicted. Across two bulbs connected in parallel the same voltage exists because the charge difference produced by the battery appears across either bulb. The voltages across two bulbs connected in series sum up to the voltage across the battery because the charge difference across the battery drops across both bulbs. A voltage is measured where a charge difference exists. The results with these operating rules are promising. The following example of a task has shown that 8th- and 9th-graders are able to use the rules correctly.

Look at the following circuit:



Insert the values of the voltage across the points
1 and 2: _____V, 2 and 3: _____V, 3 and 4: _____V

Now a second bulb of the same type is added:



Insert the values of the voltage across the points
1 and 2: _____V, 2 and 3: _____V, 3 and 4: _____V

Fig. 2 Voltages in a circuit

About 90 % of correct answers for part 1 and about 52 % for part 2 were achieved in different groups directly after instruction whereas students without experience with voltages in a circuit generally could not solve part 1 of this task. In a smaller sample of 56 students the percentage of correct answers decreased to 70 % and 22 % four month after instruction.

Even more important is the fact that some students may use spontaneously the voltage concept 4 month after instruction when they were confronted with the problem of figure 11 and when exposed to the following question: When the current circulates and the current has the same value everywhere in the circuit what does it mean "the battery becomes unusable"? Here are some answers from students of the "Realschule" (technical school).

- In the battery a chemical reaction occurs and in this way a current is produced. When this reaction comes to an end no longer is a charge difference formed.
  What was our expression for charge difference?
  The unit was volt.
  And what was the name of the term?
  Voltage.
- The battery resembles two linked water vessels. When the two vessels are connected the water level equalizes.
  What corresponds to the level difference in the battery?
  The voltage.
- In the battery is a chemical liquid. The electrons which emerge from the negative pole accumulate there. They flow to the positive pole and back through the liquid. When the liquid comes to an end the voltage is zero.

It should be emphasized that the instruction of these students contained an explicit discussion of the different views of the processes in a circuit (energy view and V/i/R-view) and the detailed application of operating rules which describe the voltage concept.

These results should be seen in connection with our hypothesis that, rather than ignoring representations and immediately introducing quantitative physics, physics instruction should aim at developing both simultaneously.A main objective should be linking representations and quantitative analysis. Our working assumption is that representation is an important cognitive component that constitutes part of the student's understanding of basic electricity.

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